THERMOSTATIC CONTROL
OF
ELECTRIC HEATING APPLIANCES

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ARMOUR INSTITUTE OF TECHNOLOGY

1917

AT 469
Prochazka, R. V.
Thermostatic control of
electric heating appliances

THERMOSTATIC CONTROL OF ELECTRIC HEATING APPLIANCES

A THESIS

PRESENTED BY

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TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN

ELECTRICAL ENGINEERING

MAY 31, 1917

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PREFACE.

The subject matter of this thesis has been presented in two separately distinct parts: part one contains a general survey of the important principles and factors governing the topic;- part two includes a general application of the field envolved in part one applied to a specific case. This part also includes the calibration of the apparatus employed in the conduction of the experimental work.

LIST OF ILLUSTRATIONS AND CURVES.

In part 1 is given a general survey of the fundamentals governing the important factors of the problem and its present application, together with the characteristic advantages and disadvantages of each application mentioned.

THERMOSTATIC CONTROL OF ELECTRIC HEATING APPLIANCES.

INTRODUCTION.

Ever since the art of automatic heat regulation began to attract attention, it has afforded men of inventive instincts a fascinating field for investigation, with the results that a great amount of time and money has been spent on appliances of more or less - mostly less - practicability. Of the hundreds of patents granted in this field, not one percent of the number have a commercial value, lacking as they do the element of practicability. Apparatus used in the automatic regulation of heat, if successful, must not only be mechanically correct and adopted to the work, but must also to an unusual degree possess the property of "persistence." It must operate in spite of neglect, interference, misunderstanding and opposition. Ranging from the stubborn person who insists that he will regulate his own heating appliances, to the misguided individual who would assist the thermostat, this instrument is

opposed by many influences that would operate to its detriment. In this connection it can readily be observed that if a heat regulating device fully accomplishes its purpose, it will so completely remove the subject of temperature from the minds of the users, of the heating appliance, that the apparatus itself may be forgotten. They may have a vague idea of the significance of the thermostat thereto attached, but consider it perhaps as only a thermometer. If questioned, they might recall that the subject of temperature never occurrs to them. Surely, under such conditions the thermostat is doing its duty and affords a sharp contrast to the unregulated appliances with its constant rising above or falling below the operating temperature, to the discomfort of the user.

With this tendency to fade out of the minds of its users, good heat regulation must have a durability and persistance of operation that is unique in mechanical work, and the purchaser of such apparatus considers not only the mechanical principles underlying it, but

also its record during years of actual service. In this investigation the above mentioned essentials were carried out as practically as was found possible.

R. V. W. Prochazka. May 1, 1917.

THE THERMOSTAT PROBLEM.- The problem of devising sensitive thermostats of great constancy has enlisted and continues to enlist the efforts of many men of science. Altho the problem is, to a large extent, a mechanical or physical one, investigators in chemical laboratories, on account of the requirements of their chemical operations, seem to have been most active in trying to solve it. In their case, however, the temperature of the body under investigation is maintained constant by conduction of heat to or from it by a suitable bath medium, and the problem therefore obviously resolves itself into maintaining constant the temperature of this bath medium in spite of the changes of temperature of the surroundings. Of course this has no direct bearing upon the thermostatic control of electrical heating appliance only in as much as the baths themselves are usually heated by electrical means.

METHODS AVAILABLE.- In general two methods of securing constant temperatures present themselves.

The first method depends upon the fact that the transition point of a pure substance with respect to two of its phases is, under suitable restricted conditions, a definite temperature, and that the transition is accompanied by a notable heat effect; the second method is of greatest interest the first method mentioned will be only briefly considered.

TRANSITION POINT METHOD.- (First Variety). The transition points that may be employed can be divided into two groups according to whether or not the temperature of transition is largely affected by changes of pressure. In the first group falls the melting point method, with the characteristic change of phase from solid to liquid. Ice and water are thus generally used for obtaining a zero temperature, and by the use of distilled water ice this temperature can be kept constant within 0:01°.

It can readily be perceived that methods of this group cannot furnish a continuous range of temperature but only a series of discrete and isolated points on the temperature scale. These points are

determined necessarily by the substances available. If the particular requirements of the investigation in hand cannot be made to conform to the selections available, then these methods fail absolutely. Further, it is obvious that this method can be used only for investigations of short duration, and requires continual attention on the part of the operator. Still, for temperatures very much below the ordinary room temperature, this procedure is in general the only one available.

SECOND VARIETY.- Into the second group, where pressure has a large influence upon transition temperature, falls the boiling point method. Only provided the pressure remains constant does the transition between liquid and saturated vapor phase take place continuously at constant temperature. For accurate regulation of temperature, therefore, any method based upon the boiling points or vapor tensions is defective because of the unavoidable variations of barometric pressure. The extent of the influence of such variations of at-

mospheric pressure may readily be perceived especially since the barometric pressure may vary several millimeters daily during fair weather and that the variation may be as high as 30 or 40 millimeters during storms.

AUTOMATIC MECHANICAL METHOD.- The automatic mechanical methods of maintaining constant temperatures will be given most space in this article since it is most extensively used in practice and bears directly upon the control of electrical heating appliances. The results of maintaining constant temperature by this method, are obtained by the employment of the automatic mechanical devices actuated by the gradual change of some physical property of a chosen substance, such physical change not being itself necessarily associated with a notable heat effect. The responsive body is usually termed the "prime control," and this is immersed in the bath medium whose temperature is to be regulated. The prime control with its operating mechanism compromisees the "regulator." For

thermostats of less accuracy the medium used is generally air.

Concomitantly with a change of temperature of its surrounding medium, therefore, the prime control or responsive body of the thermostat must change notably in respect of some physical property. In particular, some part of it may change in volume, length, pressure, vapor pressure, thermoelectric power, or electrical conductivity, and this alteration actuates a system which adds more heat thru a suitable heater or else stops this inflow of heat in such a way as to compensate for the change of heat content that the appliance would tend to suffer if unregulated. Consequently, it will be seen, that all such regulators suffer, in principle from the defect that every change in the condition of the thermostat which they are designed to prevent, must of necessity, have already occurred to some extent before the control mechanism becomes operative. The ideal thermostat would be one in which the outflow of heat in each

infinitesimal period of time was precisely equalled by the inflow simultaneously supplied by the automatic heater. In practice, however, the heat lost from the bath in a short finite interval of time is replaced by the heater in the succeeding short interval. Other conditions being favorable, the more nearly these intervals of time approach infinitesimals, the more nearly will the thermo regulator approach perfection. For a perfect thermostat the heat inflow would thus cease to be intermittent and become continuous. Viewing the matter otherwise, it is clear that the total heat lost per hour from the appliance must be gained from the heater; the loss is a continuous and not an intermittent loss, when the appliance is in operation; and a continuous loss can be compensated perfectly by a continuous gain.only.

THE PRIME CONTROL.- As a matter of history the only thermally varying properties of matter that have previously been used in the prime control of thermostats are (a) pressure of a gas, (b) pressure of a liquid,

(c) electrical conductivity, (d) thermoelectric power, (e) linear expansion of a tube, rod, or strip, (f) cubical expansion of a liquid. Each one of these properties has been utilized by some investigator in this service depending upon the nature and reliability of the service it was to perform.

All of the above mentioned properties probably could not be employed to regulate electrical heating appliances by direct application but in modified forms they might be made to operate magnetic relays which in turn could cut out or throw in a number of heating elements.

One of the main difficulties experienced in the use of relays for such purposes is the excessive arcing encountered in rupturing the currents in these elements. Since the power of the electromagnet of the relay, whose duty it is to pull open or close the contactor points, as the case may be, does not increase with increased time of action, the mechanism is altogether unable to retrieve itself when adhesion has once

occurred. The use of a more powerful electromagnet for overcoming such accidental adhesions would necessarily lead to increased self induction which in turn would increase the arcing at the contacts of the inductive circuit.

THE THERMAL RELAY.- To overcome the defects of the magnetic relay a thermal relay is sometime employed, this relay can be actuated by a regulator circuit that may be wound non-inductively. The power of this relay has a time factor, and for this reason, the longer the contact points in the heating circuit remain adherent when they should be separated, the greater does the separating force become.

A diagrammatic sketch of such a relay is shown in Fig. 1. It consists of two similar brass tubes, which may be termed expansion and compensation tubes, these are supported as shown. The lower ends of both tubes are free to move up and down, but are prohibited from lateral motion by the fixed blocks indicated in the sketch. The compensating tube carries the fulcrum of the multiplying lever, which is operated

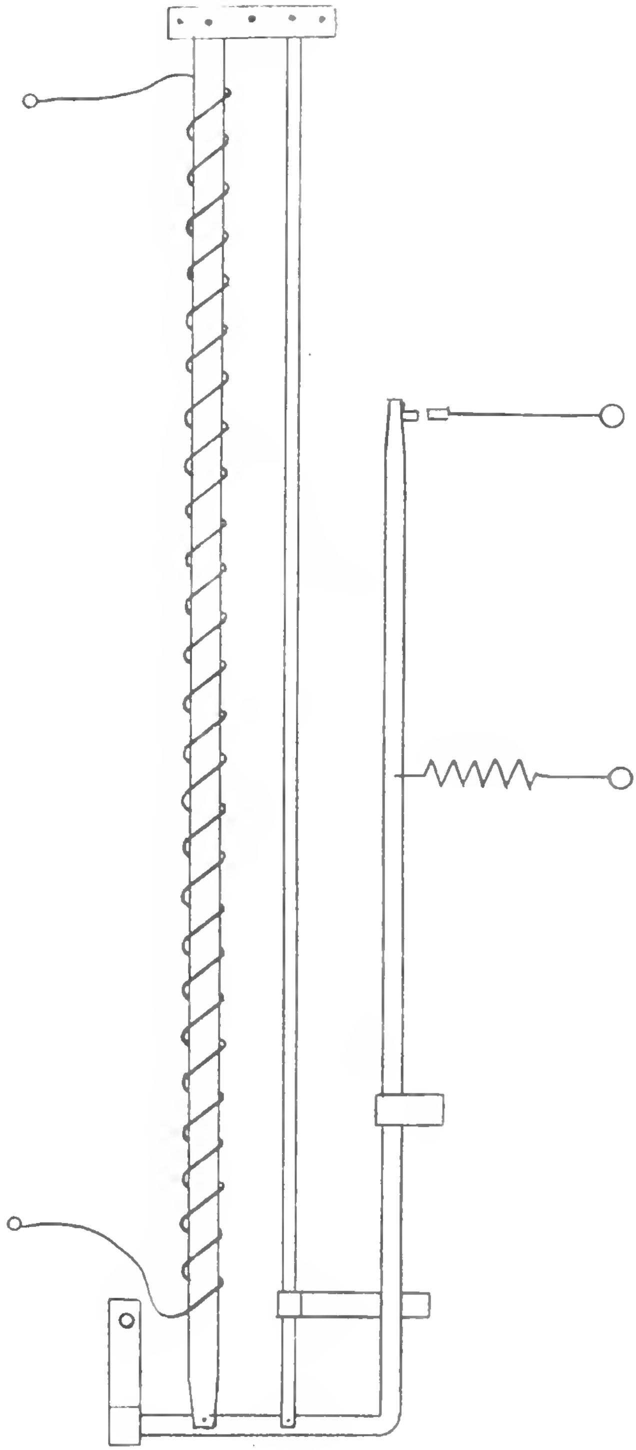

FIG. 1
THERMAL RELAY.

by the expansion tube. To insure a rapid response to the expansion or contraction of the tubes, air holes might be provided at each end or the tubes might also be perferrated. The expansion tube is wound non-inductively with insulated resistance wire which forms part of the control circuit that is closed by the contact operated by the prime control. The automatic closure of this circuit causes the heating of the expansion tube which in consequence rotates the lever so as to break the contact in the circuit of the heating elements. If this scheme is carefully analysed it can be seen that if the regulator circuit for some reason be permitted to remain closed overlong, the expansion tube would become unduly heated, not only would this cause damage to the insultation of the resistance wire, but would also lengthen the time of cooling required to effect the closure of the heat circuit, which should occur as soon as the control circuit is open. For these reasons this relay might not be very satisfactory for

controlling electrical heating appliances and to add the necessary modification for application to same would introduce too many complications to make the system practical. Altho all the resistances in the relay as well as in the heaters are non-inductive, with consequent great reduction of arcing on breaking of contacts nevertheless the disadvantages introduced by the complications would greatly outweigh this single advantage. For these reasons it is rather difficult to side step the magnetic relay for its use in controlling the circuits of the regulating portion of the heating elements.

There are a number of devices employed to minimize this objectional arcing caused at the contacts at breaking the circuit, beside the one mentioned above. Some of these are as follows;-

If only the lowest e.m.f. are used in the circuit, the voltage at "break" tho multiplied by self-induction cannot rise as high as it would if higher e.m.f.'s were employed.

Condensers may be used, but when a condenser has sufficient capacity to absorb the large quantity of induced electricity at the "break," then a spark occurs at the "make" whose effects are almost as destructive as would be those of the arc.

The needle mercury contactor has proven itself to be of great value in many instances but due to the jarring and shifting that electrical heating appliances receive while in operation,its employment in connection with same would be very impractical.

After carefully considering the above discussed advantages and disadvantages the employment of the magnetic relay seemed to be the most advantages especially for its use in controlling "electrical heating appliances." In the following pages will be given a short discussion on the way the problem was faced.

INVAR.- Invar is a nickel alloy, which is characterized by an extraordinarily low coefficient of expansion at ordinary temperatures. The analysis for this alloy is about as follows:- carbon, 18%; nickel, 35.5%; manganese, 42%, - the other elements being very low. Guillaume gives the mean coefficient of expansion for an alloy containing 35.6% nickel as $(0.877+0.00117\ t)^{10-6}$ between temperatures 0°C. and t°C. where t does not exceed 200°C. The expansion of invar as compared with ordinary steel is about as 1:11.5; with brass, as 1:17.2. Alloys either richer or poorer in nickel show much greater expansion, and the alloy containing 47.5% nickel, known as "Platinite," has the same coefficient of expansion as platinum and glass. The Bureau of Standards found the coefficient of expansion of "Invar", to range from 0.000,000,374 to 0.000,000,44 for 1°C.

INVAR-BRASS THERMAL STRIP.- A brass-invar strip was employed in conducting an experiment for regulating the temperature of an electrically heated flat

iron, mentioned in the following pages. Before depending absolutely upon the reliability of such a combination, a series of experiments was conducted upon this strip, by immersing it in an oil bath and heating it up to a temperature of $270^{\circ}C$. taking simultaneous readings of the deflections for each 5° change in temperature. To accomplish this calibration the strip was mounted on a counterweight and an indicator was attached to the end of the strip, this pointer was so mounted as to move along a scale divided into 0.5° spaces. A drawing of the apparatus combination is shown in Fig. 2. and a curve showing the relation between the deflection and variation in temperature is shown in Fig. 3. The constancy of the readings for the various runs can be observed from the following tables of data.

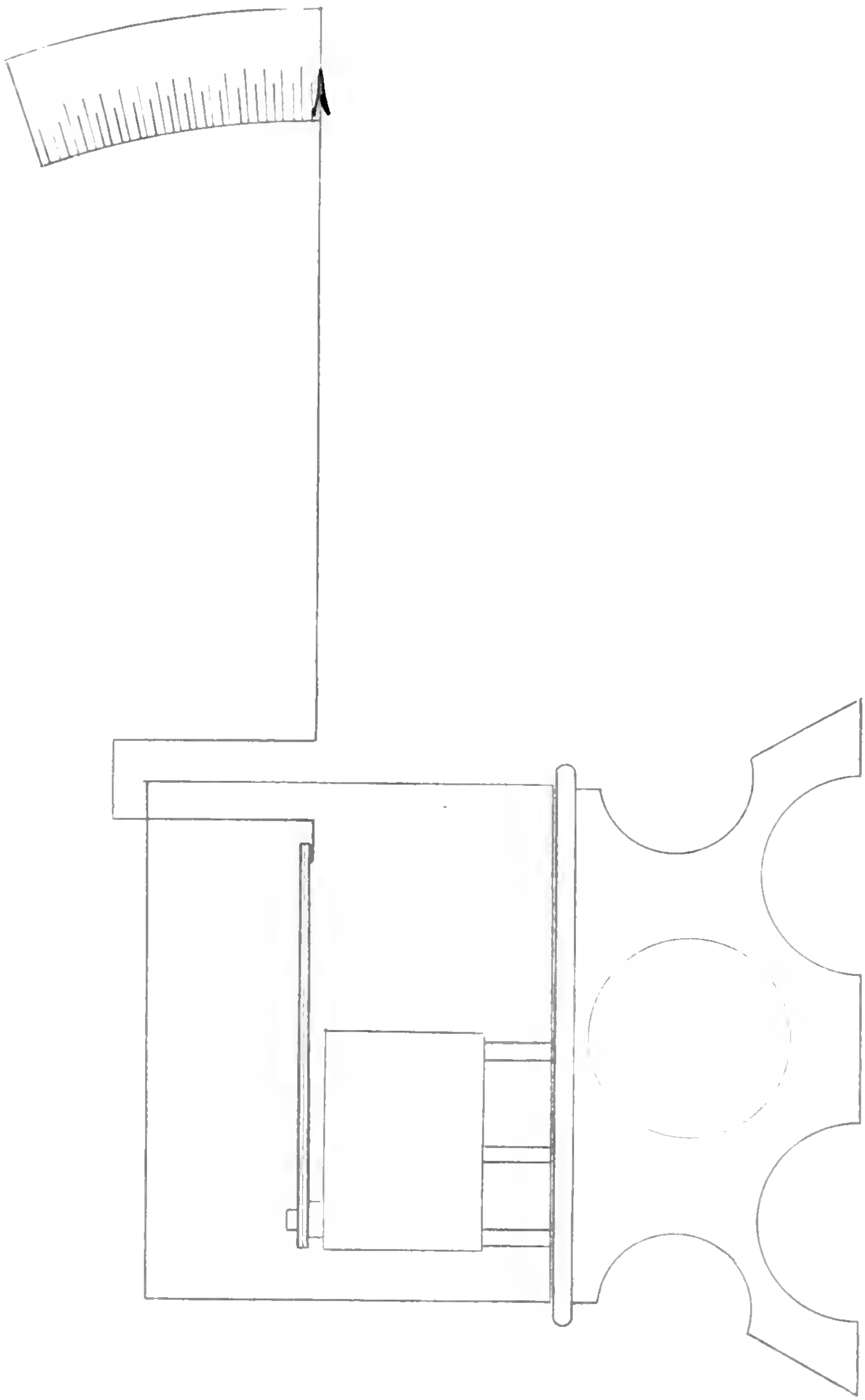

FIG. 2

FIRST RUN.		SECOND RUN.		THIRD RUN.	
Temperature C.	Deflection Degrees.	Temperature C.	Deflection Degrees.	Temperature C.	Deflection Degrees.
41	0.0	35	0.0	30	0.0
51	0.5	45	0.5	41	0.5
62	1.0	55	1.5	51	1.0
71	1.5	65	2.0	61	1.5
81	2.0	75	2.5	70	2.0
92	2.5	85	3.0	80	2.5
103	3.0	95	3.5	91	3.0
113	3.5	106	4.0	102	3.5
124	4.0	117	4.5	113	4.0
134	4.5	128	5.0	124	4.5
145	5.0	139	5.5	135	5.0
155	5.5	150	6.0	145	5.5
166	6.0	161	6.5	155	6.0
176	6.5	172	7.0	166	6.5
186	7.0	183	7.5	176	7.0
197	7.5	193	8.0	186	7.5
208	8.0	204	8.5	196	8.0
218	9.0	215	9.0	207	8.5
229	10.0	225	9.5	217	9.0
240	10.5	236	10.0	228	9.5
251	11.0	247	10.5	238	10.0
262	11.5	257	11.0	248	10.5
272	12.0	267	11.5	258	11.0

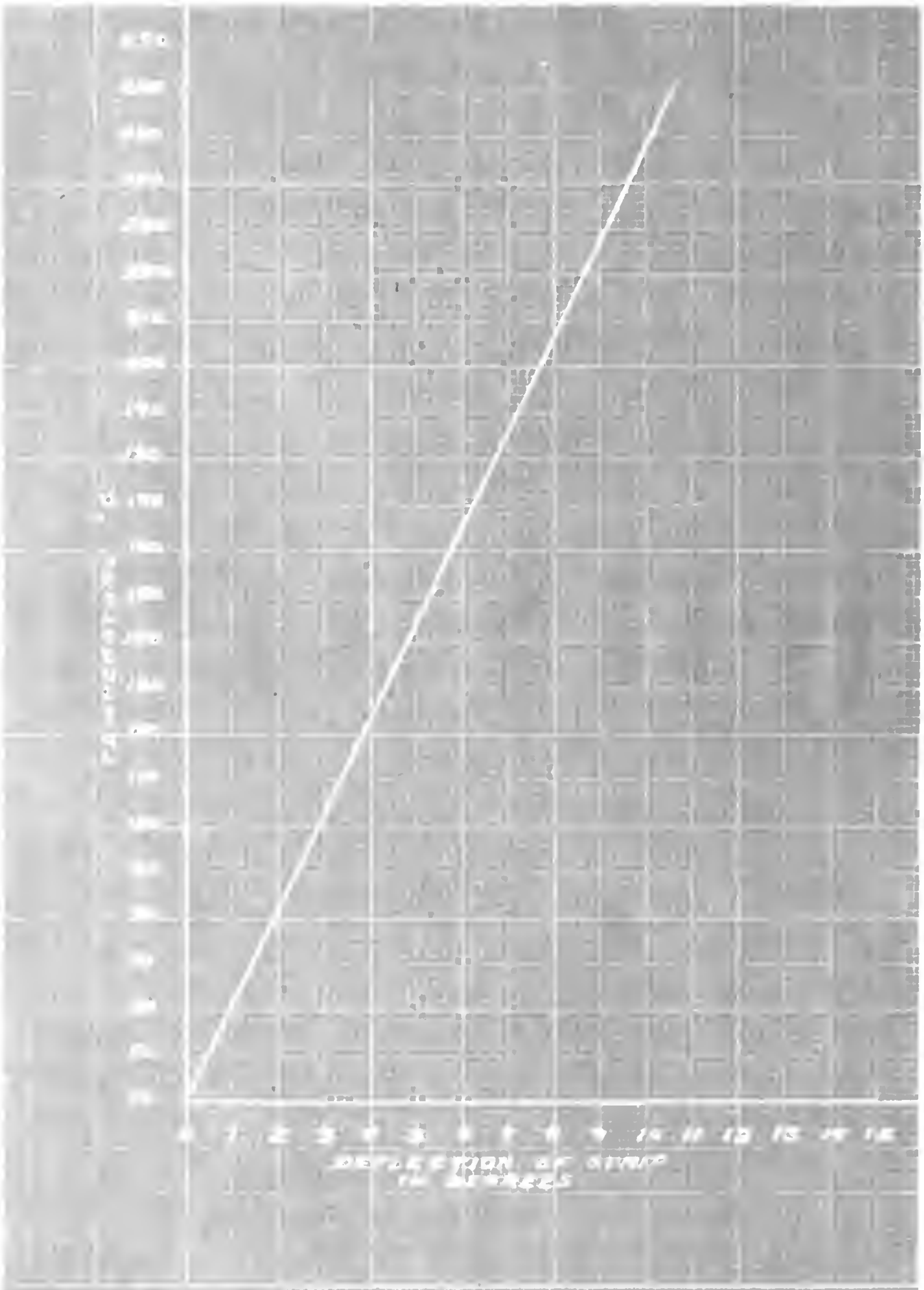

Fig. 3.

Calibration Curve of Thermal Strip.

THE THERMAL STRIP COMBINATION.- The employment of such a strip as mentioned above is shown in the sketch, Fig. 4. The operation is as follows:- When the heater is first connected to the line the strip is in its normal position, that is flat against the surface of the heater, in contact with the heating element, and the contact at A is then open. When the temperature of the appliance reaches the point of the maximum value which it is desired that it should maintain constant the adjustment of the contact point is such as to close at A. This shunts the magnetic relay which will cause the magnet to de-energize and the spring to release, the armature thus opening the circuit thru the auxiliary heating element. When the contact is broken at A, due to the tendency of the strip to assume its normal position, as soon as the temperature falls below that value which the thermostat is to regulate, the magnet will be energized and will close the circuit thru the upper element by attracting the armature mounted above.

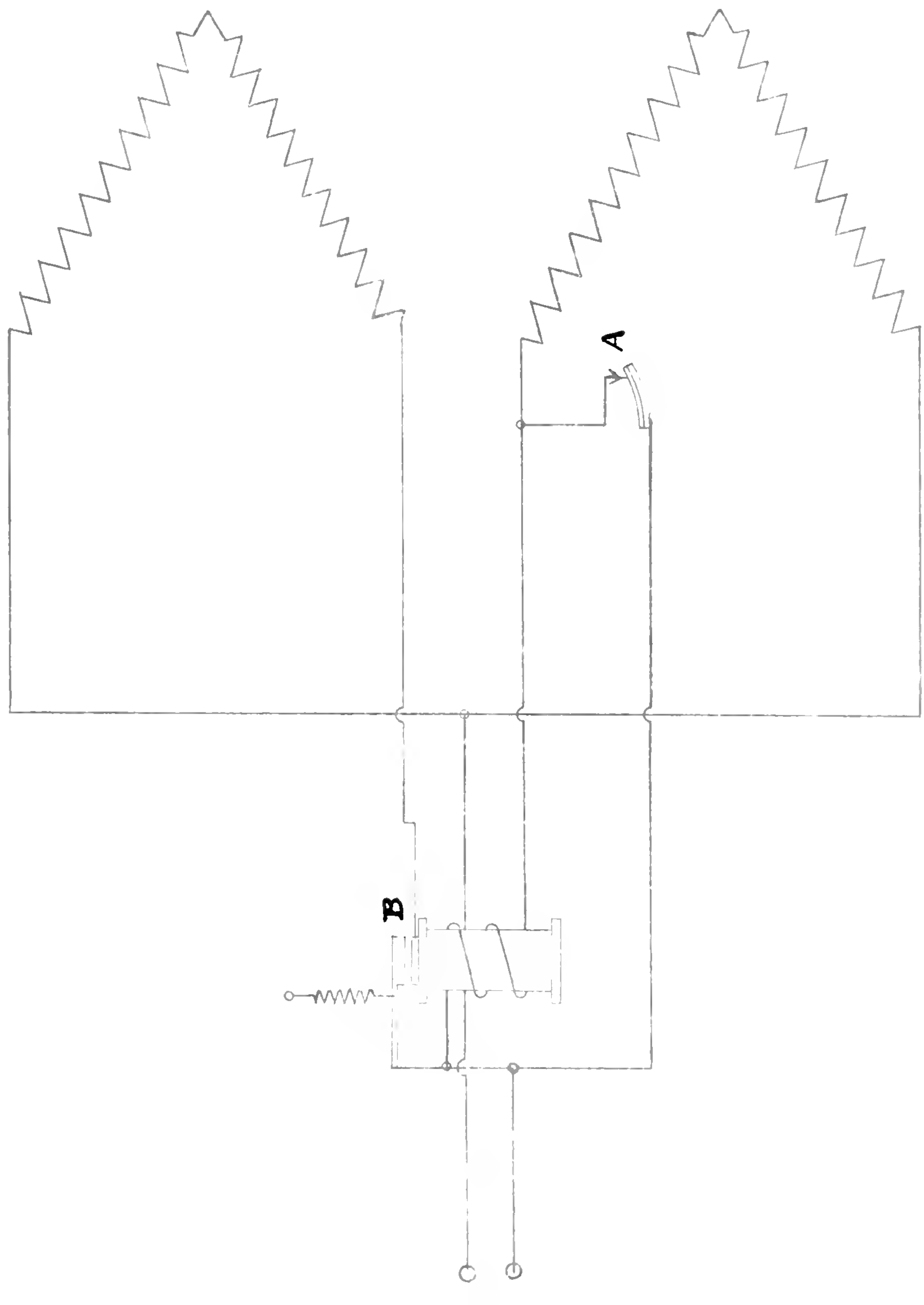

FIG. 4

MULTIPLYING LEVER.- To bring about a quick rupture of the current in the upper circuit and to minimize the arcing considerably, the electromagnet was designed to attract the armature with a force of a half pound at a distance of one eighth inch. The core of the magnet was a half inch in diameter thus allowing the current density to be of a low value, since the above element in the case of an electric flat iron which was experimented upon, was a two hundred fifty watt heater. Since trouble might be encountered due to the slowness of breaking the circuit at A, to cut down the arcing a "multiplying lever," might be advantageously employed.

The magnet for the relay has a three inch core, one half inch in diameter (one half inch diameter core was chosen as mentioned above, to lessen the current density at contact); The magnet was wound with No.18 double cotton covered copper wire. The number of turns required to exert a force of attraction of a half pound on the armature at a distance of one eighth inch from the core when carrying a current of two and

one half amperes was found from the relation

$$F\ (\text{lbs.}) = S\left(\frac{N\ I}{L\ C}\right)^2$$

Where S is the cross sectional area of the core in square inches, I is the current in amperes, N is the number of turns, L is the length of the air gap in inches and C is a constant which depends upon the properties of the magnet, the materials used in the degree of saturation. For ordinary soft iron C = 2600. Substituting these values in the above formula and solving for N, I find its value to be 650 turns. A drawing of this magnetic relay is shown in Fig. 5.

Due to the slowness of the response of the thermal strip with a variation in temperature of the appliance, in order to increase the rapidity of response and sensitiveness of the combination, the distortion of the strip may be made to react upon a multiplying lever as shown in Fig. 6. This combination would not only increase the sensitiveness and rapidity of response but would

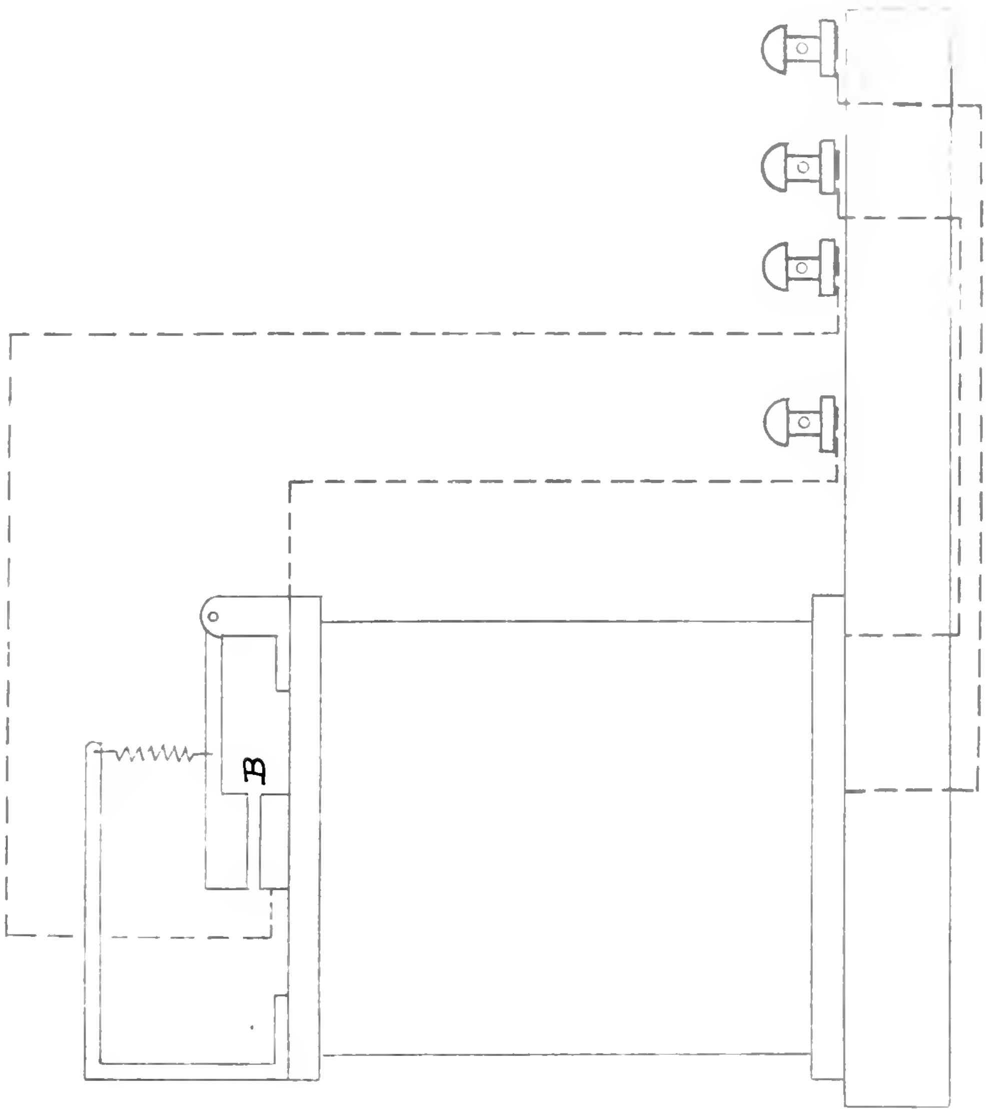

FIG. 5
MAGNET RELAY

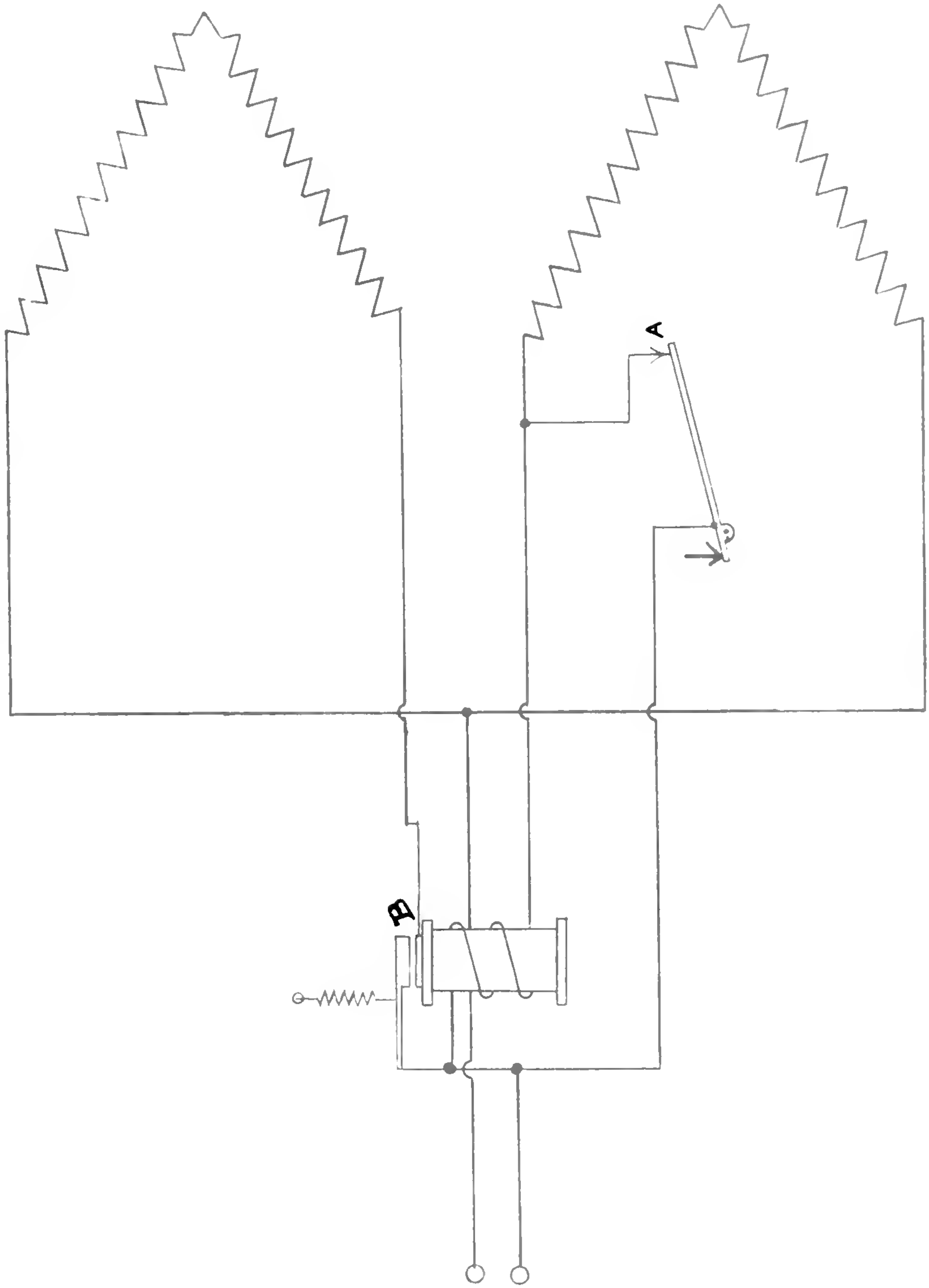

FIG. 6.

also minimize the arcing at these points thus being of a triple advantage over that shown in Fig. 4.

PARALLEL INVAR BAND METHOD.- Another method in which the differences in the coefficients of expansions could be employed to affect the operation of a magnetic relay is shown in the drawing Fig.7. A is the base plate of the flat iron, B is a strip of some metal preferably invar whose coefficient of expansion is much less than that of the metallic base plate. The strip B is rivited to the base as shown, and when the iron is heated, since the base will expand more rapidly than the strip B, this strip will tend to approach the surface of the base. By mounting a pin C on this strip the motion of the same caused by this action can be made to control the circuit of an auxiliary heating element, by proper adjustment. The device as shown in Fig. 7 would of course not be a very sensitive one but could be made so by having the pin C act upon a multiplying lever as shown in Fig. 7A., and have this lever control

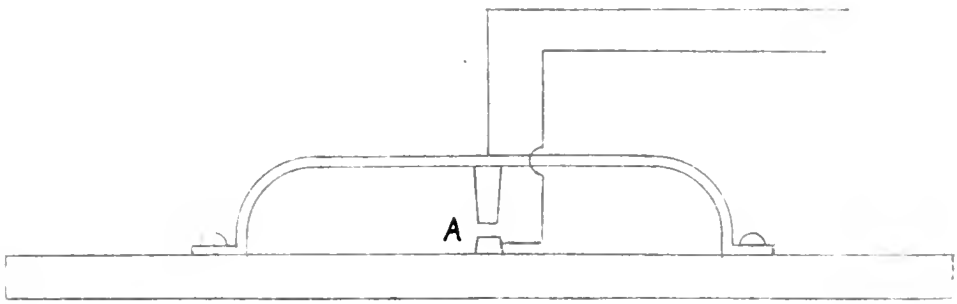

FIG. 7

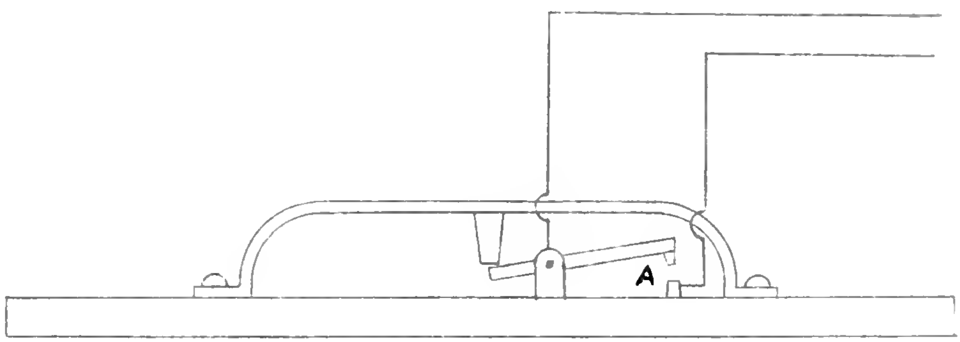

FIG. 7 A

the circuit of the auxiliary heating element. By using a multiplying lever of the proper ratio the arcing at these contact points could be sufficiently minimized to prevent serious trouble.

The solenoid of the magnetic relay shown in Fig. 5. was connected in series with one portion of the heating element and the other portion of the heating element was connected in the circuit of the relay contact points.

In order to measure the temperature of the iron, under operating conditions of the relay, a thermo-couple consisting of "advance" metal ribbon and copper strip terminals was employed. One end of this couple was placed directly within the flat iron and the other end was immersed into a beaker of ice shavings. The copper terminals from this thermo-couple were then connected directly to a milli-voltmeter. The apparatus was then connected to the line and the iron allowed to heat up until the distortion of the thermal-strip closed the circuit thru the contact mounted above, and by so doing shunting the magnet of the relay, thus causing the auxiliary heating element to be cut out of the circuit. The milli-voltmeter reading at the instant of operation of the relay was recorded both when the auxiliary or regu-

lating heating element was cut out of, or cut into the circuit.

Three sets of readings were obtained for different settings of temperature were obtained by changing the position of contact screw mounted inside of the flat iron above the thermal strips. The constancy of temperature regulation, by this device, can be observed from the curves in Figs.8, 9, and 10 which were plotted for the readings obtained for these various runs, mentioned above. The relay operated very satisfactory both in cutting out and throwing in the regulating heating element and no trouble was encountered in rupturing the arc in either case. In working the flat iron at about 550^{0} F which is considerably above normal operating temperature of same, a little trouble was caused at the contacts due to formation of an oxide of the metals. Under actual applications this could readily be avoided by having the contacts coated with platinum or tungsten.

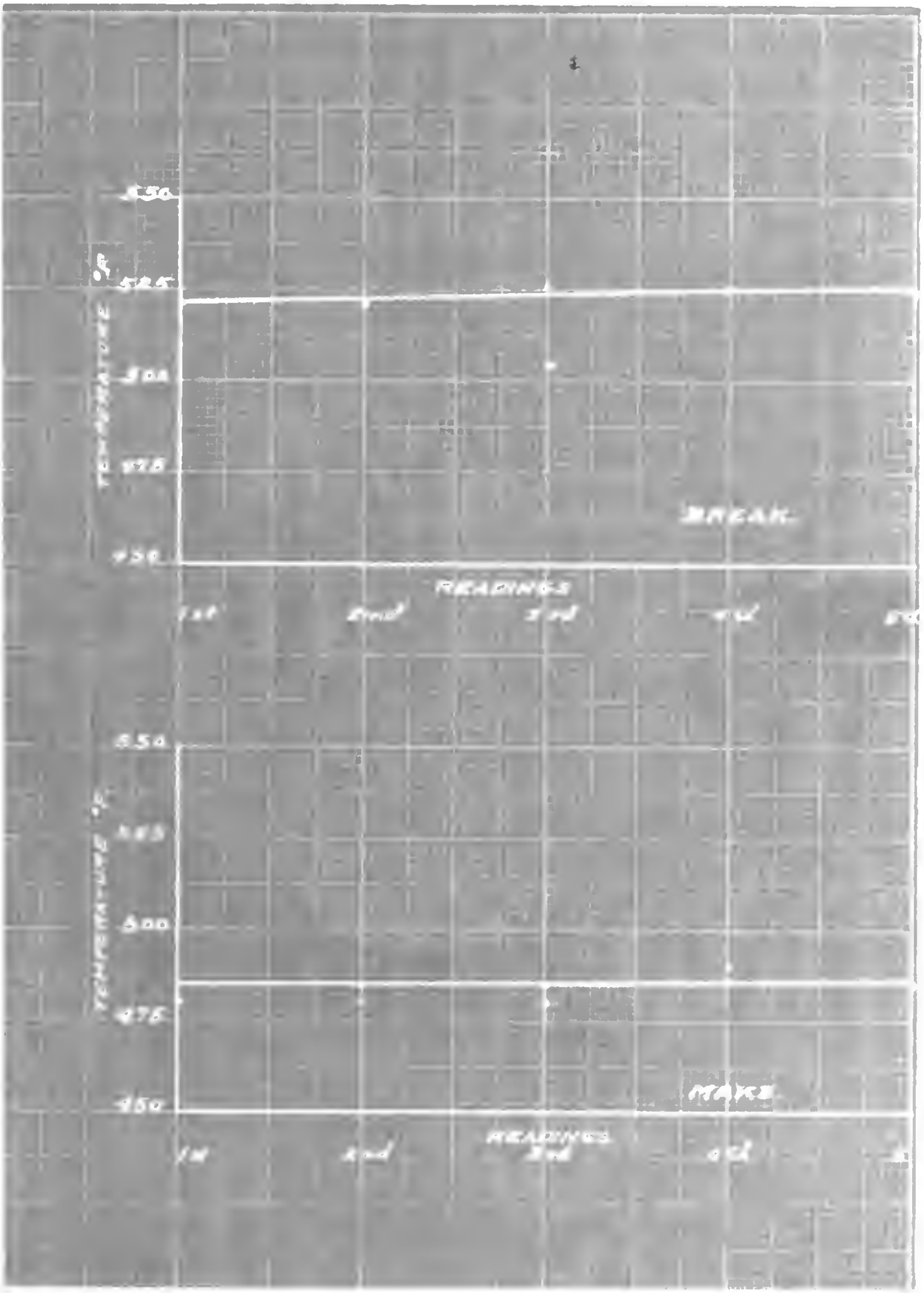

Fig. 8.

Regulation Curve.

First Run.

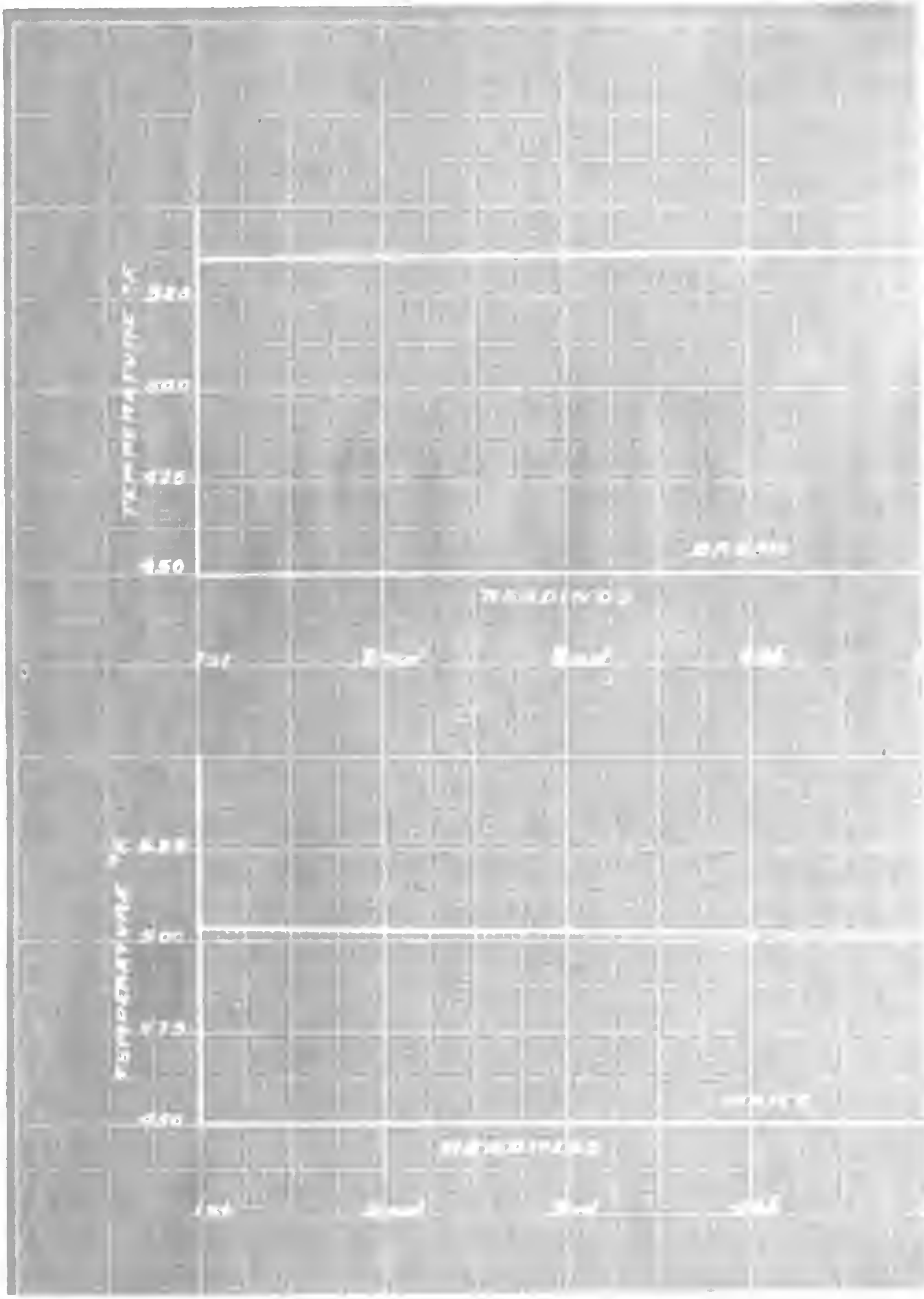

Fig. 9.

Regulation Curve.

Second Run.

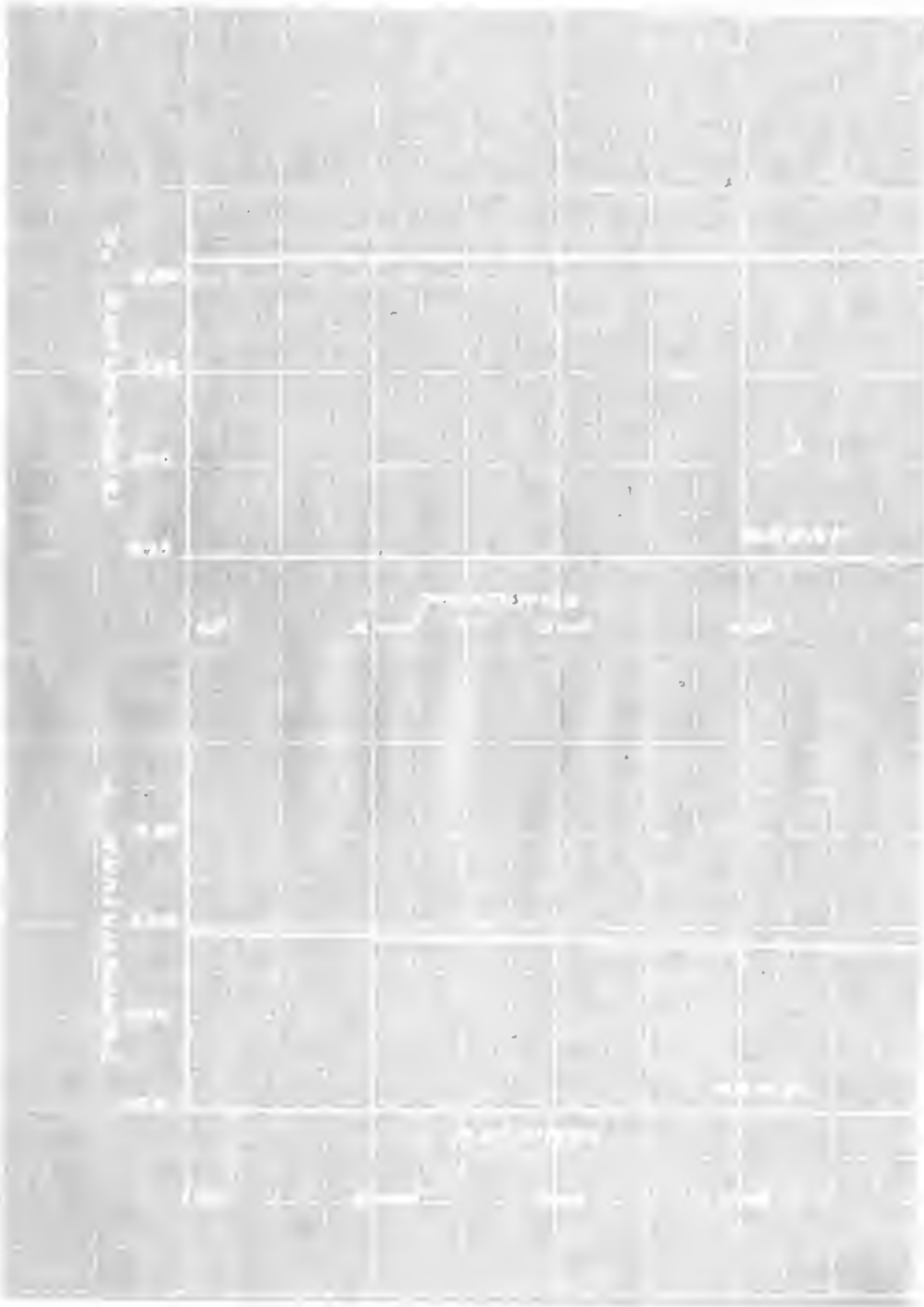

Fig. 10.

Regulation Curve.

Third Run.

Observing the data obtained for the various runs it will be seen that the temperature in the first run was maintained practically constant the variation being 45°F in 530°F or within about 8.5%; in the second run 40°F in 540°F or within about 7.5%; and in the third run 37°F in 552°F or within about 6.7% variation. From the above results it seems that the percent variation decreases with an increase in temperature. These percentages do not show the regulation to be very constant but by employing a more delicate relay and a thermal-strip made up of thin strips the sensitiveness of the device could be increased almost to any desired degree. For the crudeness of the equipment employed these results are much better than was expected. It may be here stated that tho the field for electrical thermostats be a barren one, from a practical point of view, by the obtaining of such satisfactory results with the above crude arrangement, these results ought surely to stimulate the inventive genius to attempt further development.

VARIATION OF TEMPERATURE OF FLAT IRON.

First Run.

Break.	Make.
9.5	8.7
9.5	8.7
9.6	8.7
9.6	8.8
9.6	8.7
Ave. 9.56	8.72
Temp. 530° F.	485°

$$\% \text{ Variation} = \frac{530 - 485}{530} = 8.5\%.$$

Second Run.

Break	Make.
9.8	9.1
9.8	9.1
9.8	9.1
9.8	9.0
9.9	9.1
Ave 9.82	9.08
Temp. 540° F.	500° F.

$$\% \text{ Variation} = \frac{540 - 500}{540} = \frac{40}{540} = 7.4\%.$$

Third Run.

Break.	Make.
10.2	9.5
10.2	9.5
10.1	9.3
10.2	9.4
10.3	9.5
Ave. 10.2	9.44
Temp. 552° F.	515° F.

$$\% \text{ Variation} = \frac{552 - 515}{552} = 6.7\%.$$

The thermo-couple was calibrated by placing one end into an oil bath and the other into ice shavings. The calibration curve for this particular couple is shown in Fig.11.

A 29.353 centemeter sample of the invar used for the brass-invar strip was placed into a water bath and the expansion measured for a variation in temperature of about 80°C. Three runs were made and from the results obtained the coefficient of expansion was found to be about 0.000,000,535.

The readings obtained were as follows.

	Range of Temperature °C.	Elongation of Sample.
	80	.001130 cm.
	80	.001190
	80	.001145
Ave.	80°	.001155

Ave. coefficient of Expansion $\frac{.0000155}{80\ 29.353} = 0.000,000,535.$

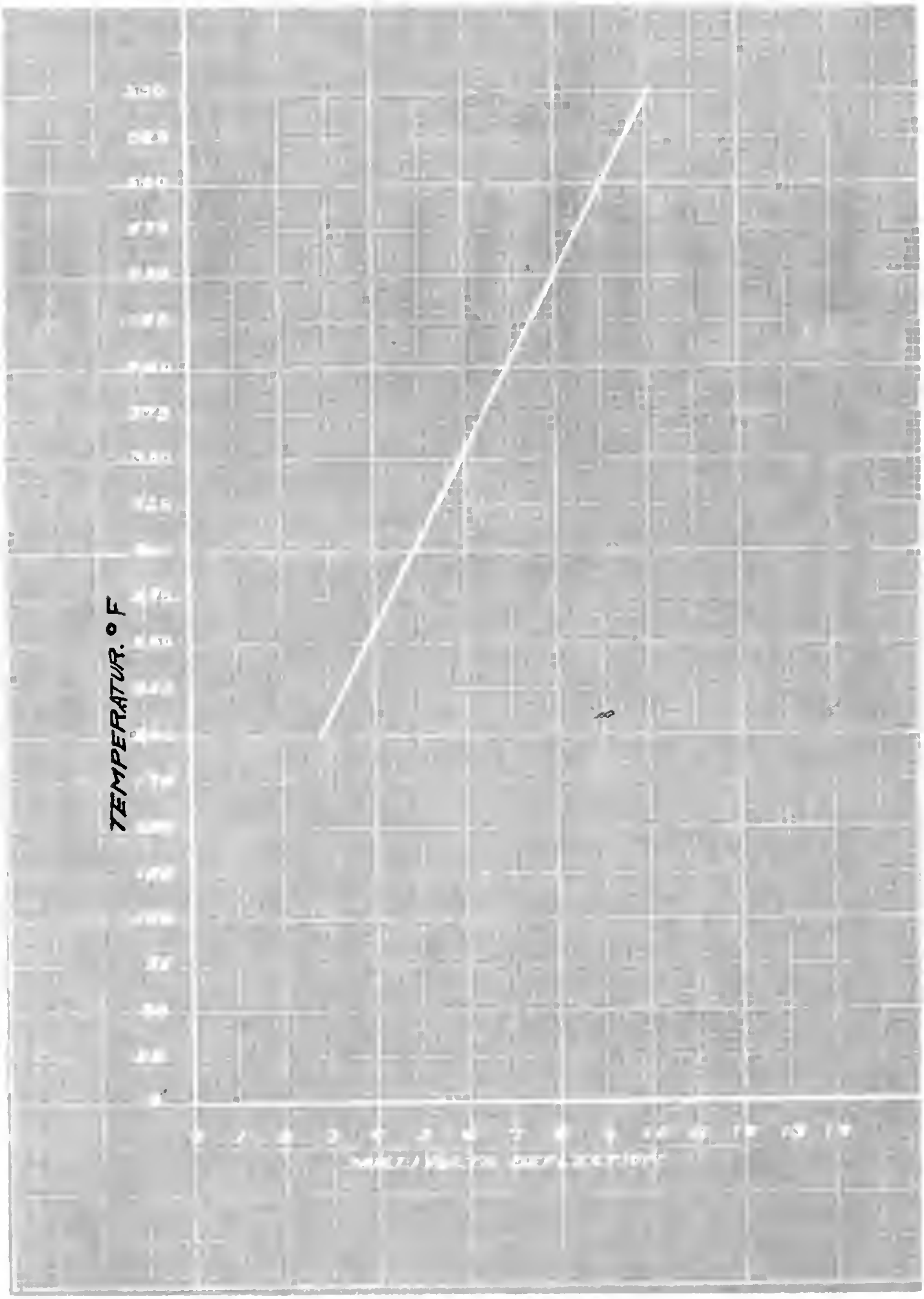

Fig. 11.

Calibration Curve of Thermo-couple.

CALIBRATION

OF THERMO-COUPLE.

TEMPERATURE °F	MILLI-VOLTS DEFLECTION.
250	3.85
300	4.87
350	5.88
400	6.75
450	8.00
500	9.10
550	10.15

APPENDIX.

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